Validation and Correction for the Terra MODIS Spatial Response

Final Report

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Abstract

The Modulation Transfer Function (MTF) describes the frequency response of an imaging system and is a standard measure of imaging system performance. It is usually measured indirectly by a Fourier transform of the sensor Spatial Response (SR), which is therefore an equivalent performance measure. This research addresses determination of the MTF for the Moderate Resolution Imaging Spectroradiometer (MODIS) Earth remote sensing system on NASA's TERRA satellite. Reliable characterization of the MODIS MTF requires analysis of many sources of information. In this research, a model, pre-launch and on-orbit measurements are used to develop a consistent characterization of the MTF. The MTF model is constrained to fit pre-launch MTF measurements. Measurement of the MODIS on-orbit MTF using an on-board calibration instrument and using Landsat-7 Enhanced Thematic Mapper (ETM+) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery as reference data, is described. Finally, the effect of the sensor MTF on a MODIS science product, the Normalized Difference Vegetation Index (NDVI), and partial correction for MTF as a way to improve NDVI accuracy, are discussed.

Description of Research

This report provides a summary of our project. For details, the reader is referred to the publications listed at the end of the report. Copies of this report and our other publications are available at *http://www.ece.arizona.edu/~dial/modis.*

Focal Plane Viewer (FPV)

The FPV software program was developed in the Digital Image and Analysis Laboratory (DIAL) at the U. of Arizona. This program is a tool developed specifically to interactively visualize the large amount of pre-launch MODIS test data. FPV saved time

and effort in analysis of the band and channel registration tests for the 36 bands. The data includes a comparison of three spatial registration data sets and a special acquisition to capture the MODIS SR low-amplitude tails, known as the Point Spread Response (PSR) data.

Spatial Registration

Using the FPV, each of the focal planes was analyzed to validate the channel (detector) registration. The results show that the measurements are consistent with the pre-launch reports. The registration data were combined with the PSR data to identify cross-talk areas.

MTF prelaunch Model

A pre-launch MTF model representing the MODIS spatial response was developed using theoretical design parameters and supplemented with pre-launch MTF measurements. The model was fitted to the pre-launch measurements and is used as the reference for on-orbit measurements and simulations. The model also serves as the basis for an MTF correction filter.

Spatial Response effect on Science Products

This analysis was performed as a collaboration between our project team and Prof. Alfredo Huete's team. We have used their field measurements of growing cotton to simulate the effects of the MODIS Far Field Response (FFR) on estimation of vegetation indices, NDVI and EVI. The FFR is the MODIS SR, including the tails. The effect on NDVI and EVI measurements is a type of "adjacency effect," since it involves neighboring pixel influences.

A correction for the MODIS SR using the MTF correction filter was shown to improve NDVI science results. The reference NDVI measurements were from ETM+, since ETM+ has 8x higher resolution than MODIS. The MTF correction produces a 20% improvement in correlation between MODIS and ETM-derived NDVI.

On-orbit Analysis (SRCA)

The SpectroRadiometric Calibration Assembly (SRCA) instrument was designed to perform spatial, radiometric and spectral in-flight calibration of MODIS. In spatial mode, it is used to characterize focal plane registration by measuring cross-track spatial shifts of each detector (channel) and in-track band shifts. The SRCA was evaluated and validated as a tool to measure the MODIS on-orbit MTF in the cross-track direction. The SRCA data are insufficiently sampled in the in-track direction for MTF analysis.

Test procedure PC17 uses the SRCA to image a 12x5km reticle onto the focal planes. The result from these light scans is the cross-track response of MODIS to the SRCA reticle edge, i.e. the MODIS Edge Spread Function (ESF). The derivative of the ESF is

the Line Spread Function (LSF), which is used to compute the cross-track MTF. The MTF profile in a given direction is the magnitude of the corresponding LSF's Fourier transform. The SRCA-measured MTF data show that the MTF is stable over at least a one year period from November 2000 to November 2001.

On-orbit Analysis (sensor comparison)

Another on-orbit technique in our project was a multi-resolution, multi-sensor comparison. This analysis also lead to a new image registration approach based on the geolocation information in the satellite imagery files. The geocoding allows for automatic image registration. The approach is supplemented with an affine geometric and radiometric registration. The procedure has been developed for the following sensor-band combinations (Table 1).

Table 1. Matching spectral bands for MODIS, ETM+ and ASTER.

Sensor	Bands (resolution in meters)				
MODIS	1 (250)	2 (250)	6 (500)	4 (500)	29 (1000)
ASTER	2 (15)	3 (15)	4 (30)	1 (15)	11 (90)
ETM+	3 (30)	4 (30)	5 (30)	2 (30)	

The MTF estimation algorithm is applied once the multi-sensor images are registered to each other. The algorithm was validated using simulations, including a special case dealing with aliasing, which is inherent in the MODIS instrument, particularly in-track.

MTF results

The on-orbit results from the sensor comparison approach are from the scenes listed in Table 2. The cross-track MTF estimates generally follow the pre-launch model, and the in-track MTF estimates are generally below the model MTF.

Table 2. MODIS, Landsat-7 ETM+, and ASTER geodetic geolocation accuracy, acquisition angle from nadir, RMS geolocation error and nominal geolocation error.

Site	Date	MODIS	ETM+		ASTER	
		RMS error (m)	angle from nadir(°)	nominal error (m)	Angle from nadir (°)	nominal error (m)
Mono Lake, CA	9/29/00	200	N/A	N/A	0.45	613[1]
Maricopa, AZ	9/26/00	200	5.2	50	N/A	N/A
Maricopa, AZ	5/24/01	50	5.2	50	N/A	N/A
Gualarajada, MX	3/29/01	50	1.3	50	N/A	N/A
Islands near Greece	2/05/02	50	N/A	N/A	5.52	613[11]

[1] Based on the magnitude of the in-track and cross-track geolocation requirement.

S.E. Odawaracho,Japan	2/15/02	50	N/A	N/A	5.28	613[11]
Australian Coast	1/01/01	50	N/A	N/A	1.46	613[11]
Tahoe, NV	8/19/01	200	N/A	N/A	1.34	613[11]
Tahoe, NV	4/16/01	200	N/A	N/A	0.65	613[11]
Tahoe, NV	2/27/01	200	N/A	N/A	0.87	613[11]

In an effort to overcome the in-track aliasing, two interleaving techniques were tested. One is a model-based approach and the other is a multi-date approach. The approaches are based on images having a high scene-to-scene radiometric correlation with similar atmospheric conditions. The work is in the initial phase and demonstrates promising results.

Significant Results

The following major accomplishments are reported during the final phase of this investigation: pre-launch characterization of the MODIS Spatial Response (SR), on-orbit characterization of the Modulation Transfer Function (MTF) for the NIR, S/MWIR and LWIR focal planes and analysis and correction of the SR effect on science products Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI).

These major accomplishments have been achieved through cooperation with other investigators: the MODIS Characterization Science Team, the Land Science Support Team, the MODIS Land Science Team and the MODIS Calibration Science Team. This research study has produced several publications: 6 at SPIE symposia, one at an IGARSS symposium, one in the special MODLAND issue of Remote Sensing of Environment, a MS thesis and a PhD dissertation.

The specific significant results from our project are:

- A model of the pre-launch MODIS MTF, which can also be used for MODIS on the Aqua platform.
- A novel image registration technique, which uses the geolocation data in the imagery files.
- Characterization of the on-orbit, cross-track MTF that indicate on-orbit performance is stable and comparable to pre-launch performance.
- Characterization of the on-orbit, in-track MTF that indicate on-orbit performance is lower than pre-launch.
- Correction for the MTF produces quantitative and qualitative improvement in vegetation index science products.

The pre-launch analysis consists of reviewing spatial registration data and modeling of the MODIS SR based on Santa Barbara's Remote Sensing MODIS MTF model. This included qualifying the pre-launch SRCA spatial mode acquisitions as an on-orbit MTF tool. The pre-launch characterization of the MTF was used to quantitatively evaluate the

effect of the SR on the NDVI and EVI, which also includes a correction to improve the accuracy.

The on-orbit analysis uses both on-orbit SRCA cross-track data and multi-sensor (ASTER and Landsat 7, ETM+) multi-resolution imagery for MTF analysis. The multi-sensor analysis is based on spectral compatibility. The on-orbit cross-track MTF measurements show less variation than the in-track MTF measurements, possibly indicating the former are more accurate. In an effort to improve the sampling rate, model and multi-date interleaving approaches were examined for MTF analysis.
The pre-launch and on-orbit measurements developed a consistent characterization of the MTF, which achieve our primary research goal, evaluation and correction of the MODIS SR. Copies of this report and our other publications are available at *http://www.ece.arizona.edu/~dial/modis*.

Graduate Students Supported

Alexandre Braga, MS Electrical and Computer Engineering, December 2000
Francisco Rojas, PhD Electrical and Computer Engineering, December 2002
Qianyi Xu, MS Electrical and Computer Engineering
Doug Rautenkranz, MS Arid Lands Resource Sciences

NASA and Science Team Interactions

Throughout project - MODIS Characterization Science Team (MCST) and Science Data Support Team (MSDST)

We worked regularly with Gerry Godden, Bruce Guenther, and Dr. Farida Adimi of the MCST. They provided data and information on the MODIS system and test results that were used by us in our own system performance analysis. We also had frequent interactions with Robert Wolfe and Mash Nishihama of the MSDST in connection with MODIS geolocation processing.

Summer 1999 - Internship with Raytheon STX (RSTX)

During the internship, Francisco Rojas joined the MODIS Land Science Support Team (LSST) at NASA/GSFC. His assigned tasks included creating 160 control point templates for the LSST MODIS Error Analysis Algorithm using the Land Control Point Matching and Correlation program (MODIS Level 1A Earth Location, Algorithm Theoretical Basis Document Version 3.0, August 1997). Creation of control point templates included auto-documenting scripts and control point images. The MODIS Land Science Support Team at NASA/GSFC supported the internship for Francisco Rojas, and the University Space Research Association supported his participation in the summer 1999 workshop on high performance computing.

During the summer, Mr. Rojas also attended the 1999 High Performance Computing Workshop, sponsored by the University Space Research Association. This experience has

enhanced our project with knowledge about parallel programming concepts and availability of tools such as the Message Passing Interface (MPI) libraries. The workshop included hands on experience on the Cray T3E and the Beowulf Linux cluster development system architectures.

August 2000, May 2001 - Jim Storey, Raytheon STX, visits to UA

Our work in image registration was led by collaboration with Jim Storey of Raytheon STX, to the U. Arizona during two visits. He assisted us with ETM+ and ASTER registration to MODIS and with MTF analysis techniques. The registration technique enables us to register images via geolocation data, without the use of control points.

We also worked with Science Team members Alfred Huete and Kurt Thome at the UA, to obtain calibrated ETM+ data and on the evaluation of MODIS MTF correction procedures in terms of vegetation indices.

Publications

Theses and Dissertations:

Alexandre Braga, MS thesis, “Modulation Transfer Function Derivation for Spatial Calibration of NASA’s Moderate Resolution Imaging Spectoradiometer (MODIS)”

Francisco Rojas, PhD dissertation, “Modulation Transfer Function Analysis of the Moderate Resolution Imaging Spectroradiometer (MODIS-AM) on the Terra Satellite”

Peer-Reviewed Journal Papers:

Francisco Rojas, Robert A. Schowengerdt and Stuart F. Biggar, "Early Results on the Characterization of the Terra MODIS Spatial Response," Remote Sensing of Environment, Vol 83/1-2, pp 50-61, 2002.

Conference Proceedings Papers:

Rojas, Francisco, R. Schowengerdt, A. Braga and S. Biggar, "Spatial Analysis of the MODIS PFM Channel Alignment and Far Field Response using Pre-resistor Fix Data," Proc. SPIE Conference on Earth Observing Systems Vol. 4135, San Diego, July 31-August 4, 2000, p60-70.

Braga, Alexandre, F. Rojas, R. Schowengerdt and S. Biggar, "Calibration of the MODIS PFM SRCA for On-orbit, Cross-track MTF Measurement," Proc. SPIE Conference on Earth Observing Systems, Vol. 4135, San Diego, July 31-August 4, 2000, p71-79.

Schowengerdt, R. A., "Measurement of the sensor spatial response for remote sensing systems," Proc. SPIE Conference on Visual Information Processing X, Vol. 4388, Orlando, April 16-20, 2001, p65-71

Rojas, F., R. A. Schowengerdt, and S. F. Biggar, "Modulation Transfer Analysis of the Moderate Resolution Imaging Spectroradiometer (MODIS)," Proc. SPIE Conference on Earth Observing Systems VI, Vol. 4483, San Diego, August 1-3, 2001, p222-230.

Schowengerdt, R. A., "Aliasing in Remote Sensing Imagery," Proc. SPIE Conference on Visual Information Processing XI, Vol. 4736, pp92-98, Orlando, April 4, 2002.

Rojas, F., R. A. Schowengerdt, S. F. Biggar, "Validation of the on-orbit Modulation Transfer Function for the Moderate Imaging Spectroradiometer (MODIS-AM) using on-orbit calibration data and high contrast imagery," Proc. IEEE Int. Geoscience and Remote Sensing Symposium (IGARRS '02), Vol. II, pp973-975, Toronto, June 24-28, 2002.

Rojas, Francisco; Schowengerdt, Robert A.; Biggar, Stuart F., "Error and correction for MODIS-AM's spatial response on the NDVI and EVI science products," Proc. SPIE Conference on Earth Observing Systems VII, Vol. 4814, Seattle, July 7-11, 2002, p447-456.